Emerging Methods of Caries Diagnosis

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Abstract:

Current diagnostic tools used in dental caries detection are not sensitive enough to diagnose the disease process in its early stages and, frequently, once a diagnosis is made restoration is the only effective means of treatment. The purpose of this review was to systematically assess the available literature for evidence to determine if emerging diagnostic methods for dental caries are more efficient than traditional methods for detecting and monitoring the progress of caries in permanent and primary teeth. Inclusion and exclusion criteria were established preceding the literature search. Included articles were grouped by type of emerging technology and study design. The types of emerging technologies included laser fluorescence, light fluorescence, digital imaging fiber optic transillumination, and ultrasound. Primarily on the basis of in vitro and preclinical data, some of the reviewed methodologies showed promising results for the detection and monitoring of early caries lesions. However very little clinical data are available to validate these emerging technologies. It was concluded that, although significant promise is apparent with these technologies, there is still not enough evidence available at this time for any of the reviewed diagnostic techniques to be recommended as a substitute for traditional diagnostic techniques.

Keywords: caries, detection, fluorescence, transillumination, ultrasound

Dental caries is an infectious disease caused by cariogenic microorganisms metabolizing fermentable carbohydrates. Thus, the diagnosis of the disease must consider not only the presence of lesions afflicting the teeth but other factors including the nature of the oral flora, dietary habits and composition, salivary flow and oral hygiene habits. However, it is also known that presence of carious lesions is the factor most indicative of the existence of the disease and this presentation focuses on evolving methods for detecting carious lesions in enamel.

Current methods for the clinical diagnosis of dental caries involve visual-tactile-radiographic procedures that have been described on numerous occasions and have been in routine use for more than half a century with very little change. While there have been improvements in such areas as intraoral illumination and the quality of the radiographs, the fundamental caries diagnosis method has remained essentially unchanged. It is also widely recognized that carious lesions cannot be detected with conventional methods until they are relatively well advanced and may involve one-third or more of the thickness of enamel. As a result it is often necessary to restore the lesion rather than attempt alternative measures to reverse or arrest the lesion.

For at least the past 20 years investigators have explored the use of alternative procedures for the detection of dental caries and this area has received significant attention during the past decade with the introduction of several instruments designed to improve caries detection. Recent technological advancements have supported the exploration of additional strategies for caries detection with a particular emphasis on the detection of caries at an earlier stage of formation.

The goal of this paper is to review the existing data regarding these evolving methods for the detection of dental caries.

METHODS

A methodical literature search was conducted in MEDLINE and EMBASE databases by Patricia Anderson, head librarian at the University of Michigan. The search strategy was broad trying to include all the relevant studies published in the literature and did not include unpublished studies. A total of 3436 published reports resulted from this search.

Selection Criteria

Because of the nature of the topic reviewed in this paper, it was necessary to relax the inclusion criteria to include in vitro studies that would not be considered acceptable evidence in reviews of other research topics that have stronger level of available evidence including clinical trials. The inclusion criteria were:

- Studies reported in peer-reviewed journals.
- Studies that involved one of the following emerging diagnostic techniques:
    - Quantitative Light-Induced Fluorescence (QLF)
    - Infrared Laser Fluorescence (DIAGNOdent)
    - Digital Imaging Fiber Optic Transillumination (DIFOTI)
    - Ultrasound
- Studies in which the results were validated with a gold standard.
- Studies in which the results reported included at least one of the following types of data: sensitivity, specificity, accuracy, correlation with gold standard, or ROC.

The 3,436 articles were screened at three different levels. In the first level, the non-relevant studies were eliminated by reading the titles of all the articles. In the second level, the remaining studies were screened by abstract content eliminating the non-relevant ones. In the third and last level of screening, the remaining articles were analyzed in detail using the previously determined inclusion criteria as the standard for acceptance for this report.

Data Collection And Analysis

The results of the selected studies were summarized and are presented in three evidence tables. Table 1 contains all the selected studies. Tables 2 and 3 grouped the articles by caries location on specific tooth surfaces (smooth surfaces or occlusal); table 2 includes the reports on smooth surfaces, while table 3 includes the reports on occlusal surfaces. Tables for approximal, root, and secondary caries were not created because of the limited number of reports. The following is the list of the criteria included in the tables to assess the reports: authors and year of publication, detection methodology, study design, type of teeth, gold standard, repeatability (intraclass), sensitivity, specificity, accuracy, correlation with gold standard, and Receiving Operator Characteristics (ROC).

RESULTS

Only thirteen publications of studies complied with the inclusion criteria. Nine of the studies reported on QLF, two on DIAGNOdent, one on QLF and DIAGNOdent, one on DIFOTI, and none on ultrasound. All of the studies were *in vitro*. Four of them were longitudinal and the remaining studies were cross-sectional studies. The results of all of these studies are

summarized in Table 1. Data from the study that reported on QLF and DIAGNOdent are included in separated rows in the table with one row presenting the QLF results and another row presenting the DIAGNOdent results.[1] l-Khateeb et al. reported data from bovine and human enamel specimens, but only data from human specimens were included in the tables [6]

Eight studies[1,2,4,5,10-12] reported sensitivity and specificity values. Accuracy values were reported for only one study,[11] while ROC values were reported in three studies.[4,5,10] Eight studies reported the correlation to the gold standard values.[1,3,5-10] Eight of the studies were in extracted human teeth, while the remaining six were in specimens from human or bovine teeth.

Results for caries detection on smooth surfaces are summarized in Table 2. Seven articles reported the results of investigations using QLF.[3,5-10] Reported sensitivity, specificity, and ROC results were very good, while correlations with gold standards were between 0.63 and 0.91. Only one article reported on the results obtained using the DIAGNOdent system. Sensitivity and specificity results were 0.75 and 0.96, respectively.[1] Correlation coefficients with the gold standards were between 0.67 and 0.86. Only one article reported the results obtained with DIFOTI, as well.[12] Sensitivity, specificity, and repeatability results were 0.43, 0.87, and 0.12, respectively.

Table 3 summarizes the reported results on caries detection on occlusal surfaces. Only one article reported results for occlusal caries detection using QLF.[4] Sensitivity, specificity, and ROC results for this method were 0.49, 0.67, and 0.78, respectively, while repeatability was between 0.53 and 0.80. Two articles[10,11] reported results for the use of the DIAGNOdent system

on occlusal surfaces. Sensitivity, specificity, ROC, and accuracy results for lesions limited to enamel were 0.42-0.87, 0.72-0.95, 0.92, and 0.79-0.84, respectively. For lesions that involved dentin, the results reported for sensitivity, specificity, ROC, and accuracy were 0.76-0.84, 0.79-1.00, 0.99, and 0.81-0.83, respectively. Repeatability was reported to be between 0.88 and 0.97. The correlation with the gold standard was 0.76-0.79. One article reported on the capability for DIFOTI to detect occlusal caries; the sensitivity, specificity, and repeatability values reported in that article were 0.67, 0.87, and 0.52, respectively.[12]

Tables summarizing the results obtained on approximal surfaces, root surfaces, and secondary caries were not created because of the limited number of reports. Detection of approximal caries was reported in two articles.[2,12] One article used QLF and reported the following values for sensitivity, specificity, and repeatability, respectively: 0.56-0.74, 0.67-0.78, and 0.00-0.67.[2] The other article that investigated caries detection on approximal surfaces used DIFOTI and reported sensitivity, specificity, and repeatability values of 0.56, 0.76, and 0.25, respectively.[12] For the detection of secondary caries, only one article reported the use of QLF to detect lesions around amalgam restorations.[7] They reported a correlation with the gold standard of 0.66. Only one article presented results for root surface caries using DIFOTI and these investigators reported sensitivity and specificity values of 0.38 and 0.84, respectively.[12]

DISCUSSION

By definition, emerging technologies are methodologies that are being developed and are not yet established through the appropriate validation studies. With regard to emerging procedures for the clinical detection of dental caries, the appropriate validation studies must

include controlled clinical trials specifically designed to demonstrate the ability of the emerging technology to accurately detect such lesions. These studies must necessarily include detection procedures that are established and are therefore considered to be “gold standards”. The appropriate design of the clinical trials will be dictated by the nature of the emerging technology and the expected developmental stage of the lesion that can be accurately detected. For example, the detection of relatively well-advanced lesions that have progressed through the enamel may be verified through the use of conventional clinical procedures while the validation of technologies expected to be capable of detecting very early lesions must utilize more innovative strategies that are established for the assessment of these types of lesions.

For this review we selected technologies that have been investigated for several years and reported at various scientific meetings with expected peer-reviewed publications to support their potential value for caries detection. We excluded electrical conductance (ECM) and fiber optic transillumination (FOTI) because the procedures have been in clinical use for a number of years and were included in the Evidence Report from the Research Triangle Institute with the conclusion that further studies are needed. As noted earlier, a methodical search of the literature revealed only a very limited number of publications and all of these publications reported the results of in vitro studies. Although the status of the development of these emerging technologies is disappointing with regard to this conference, it must be recognized that these in vitro investigations are critically important to verify the potential ability of the emerging technology to detect caries and to permit the appropriate design of subsequent clinical validation studies. Moreover, the results observed using quantitative light-induced fluorescence (QLF)

meaurements in small-scale clinical trials in Sweden[13] and Indiana[14] further support the potential ability of this method for early caries detection as well as monitoring lesion progression *in situ*. The available data from the published in vitro investigations presented in the foregoing tables clearly support the potential ability of three of the emerging technologies for caries detection, namely quantitative light-induced fluorescence (QLF), infrared laser fluorescence (DIAGNOdent), and digital imaging fiber optic transillumination (DIFOTI). Each of these technologies has demonstrated a reasonable level of accuracy (sensitivity and specificity) compared to appropriate in vitro gold standards of histology, microradiography, and/or confocal laser scanning microscopy. The future of these emerging technologies for caries detection will depend on the results of carefully designed and controlled clinical trials with validation using the appropriate gold standards.[15] It is notable and timely that within the past month the NIDCR has funded clinical validation studies at Indiana, Iowa, and Texas to determine the validity of these methods except for ultrasound. These investigations will involve children who will be examined each six months using each of the evolving methods as well as conventional procedures independently. Exfoliated deciduous teeth will be sectioned and examined using polarized light microscopy as the gold standard to determine the presence or absence of dental caries. Investigations of this nature are critically needed to validate these and future technologies for the detection of dental caries.

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Table 1. Summary of All Published Studies on Selected Emerging Technologies

Reference	Methodology	Type of Study	Type of Teeth	Caries location	Gold Standard	Repeatibility	Sensitivity	Specificity	Accuracy	Correlation with Gold Stardard	ROC
Shi et al., 2001[1]	QLF	Cross Sectional - In vitro	Human Premolars	Smooth Surfaces	TMR & Histology	-	D=0.94	D=1.00	-	Hist.+TMR depth=0.88; Only E: TMR Depth=0.91; DZ=0.75	-
Eggertsson et al., 1999[2]	QLF	Cross Sectional - In vitro	Human Premolars and Molars	Approximal	CLSM	0.00-0.67	0.56-0.74	0.67-0.78	-	-	-
Lagerweij et al., 1999[3]	QLF	Cross Sectional - In vitro	Enamel Specimens	Smooth Surfaces	TMR	-	-	-	-	0.63	-
Ferreira-Zandona et al., 1998[4]	QLF	Cross Sectional - In vitro	Human Premolars	Occlusal	CLSM & Histology	0.53-0.80	0.49	0.67	-	-	0.78
Ando et al., 1997[5]	QLF	Longitudinal (Prospective) - In vitro	Bovine Specimens	Smooth Surfaces	CLSM & TMR	-	0.94-0.98	0-1.00	-	TMR DZ=0.69; CLSM depth= 0.76	0.95
Al-Khateeb et al., 1997[6]	QLF	Cross Sectional - In vitro	Enamel Specimens	Smooth Surfaces	TMR	-	-	-	-	TMR= 0.84	-
Hall et al., 1997[7]	QLF	Longitudinal (Prospective) - In vitro	Bovine Specimens	Smooth Surfaces	Histology & TMR	-				Histology=0.70 TMR DZ=0.83	
Hall et al., 1997[7]	QLF	Longitudinal (Prospective) - In vitro	Bovine Specimens	Secondary Caries	TMR	-	-	-	-	0.66	
Emami et al., 1996[8]	QLF	Cross Sectional - In vitro	Human Premolars	Smooth Surfaces	LMR	-	-	-	-	0.73	-
Hafstrom-Bjorkman et al., 1992[9]	QLF	Longitudinal (Prospective) - In vitro	Enamel Specimens	Smooth Surfaces	LMR	-	-	-	-	0.86	-
Shi et al., 2001[10]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars	Occlusal	TMR	0.96-0.97	E=0.42-0.46 D=0.78-0.82	E=0.95 D=1.00	-	0.76-0.79	E=0.92 D=0.99 Total=0.96
Shi et al., 2000[1]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars and Molars	Smooth Surfaces	TMR & Histology	-	D=0.75	D=0.96	-	Hist.+TMR depth=0.85; Only E: TMR Depth=0.86; DZ=0.67	
Lussi et al., 1999[11]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars and Molars	Occlusal	TMR & Histology	Enamel=0.88; Dentin=0.90	E=0.83-0.87; D=76-0.84	E=0.72-0.78; D=79-0.87	E=0.79-0.84; D=0.81-0.83	-	-
Schneiderman et al., 1997[12]	DIFOTI	Cross Sectional - In vitro	Human Anterior and Posterior Teeth	Approximal; Occlusal, Root, Smooth Surfaces	Histology	A=0.25; O=0.52; SS=0.12	A=0.56; O=0.67; SS=0.43; RS=0.38	A=0.76; O=0.87; SS=0.87; RS=0.84	-	-	-

E = Enamel; D = Dentin

Table 2. Summary of Studies Conducted on Smooth Surfaces

Reference	Methodology	Type of Study	Type of Teeth	Gold Standard	Repeatibility	Sensitivity	Specificity	Accuracy	Correlation with Gold Stardard	ROC
Shi et al., 2001[10]	QLF	Cross Sectional - In vitro	Human Premolars	TMR & Histology	-	D=0.94	D=1.00	-	Hist.+TMR depth=0.88; Only E: TMR Depth=0.91; DZ=0.75	-
Lagerweij et al., 1999[3]	QLF	Cross Sectional - In vitro	Enamel Specimens	TMR	-	-	-	-	0.63	-
Ando et al., 1997[5]	QLF	Longitudinal (Prospective) - In vitro	Bovine Specimens	CLSM & TMR	-	0.94-0.98	0-1.00	-	TMR DZ=0.69; CLSM depth= 0.76	0.95
Al-Khateeb et al., 1997[6]	QLF	Cross Sectional - In vitro	Enamel Specimens	TMR	-	-	-	-	TMR= 0.84	-
Hall et al., 1997[7]	QLF	Longitudinal (Prospective) - In vitro	Bovine Specimens	Histology & TMR	-				Histology=0.70 TMR DZ=0.83	
Emami et al., 1996[8]	QLF	Cross Sectional - In vitro	Human Premolars	LMR	-	-	-	-	0.73	-
Hafstrom-Bjorkman et al., 1992[9]	QLF	Longitudinal (Prospective) - In vitro	Enamel Specimens	LMR	-	-	-	-	0.86	-
Shi et al., 2000[1]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars and Molars	TMR & Histology	-	D=0.75	D=0.96	-	Hist.+TMR depth=0.85; Only E: TMR Depth=0.86; DZ=0.67	
Schneiderman et al., 1997[12]	DIFOTI	Cross Sectional - In vitro	Human Anterior and Posterior Teeth	Histology	0.12	0.43	0.87	-	-	-

E = Enamel; D = Dentin

Table 3. Summary of Studies Conducted on Occlusal Surfaces

Reference	Methodology	Type of Study	Type of Teeth	Gold Standard	Repeatibility	Sensitivity	Specificity	Accuracy	Correlation with Gold Stardard	ROC
Ferreira-Zandona et al., 1998[4]	QLF	Cross Sectional - In vitro	Human Premolars	CLSM & Histology	0.53-0.80	0.49	0.67	-	-	0.78
Shi et al., 2001[10]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars	TMR	0.96-0.97	E=0.42-0.46 D=0.78-0.82	E=0.95 D=1.00	-	0.76-0.79	E=0.92 D=0.99 Total=0.96
Lussi et al., 1999[11]	DIAGNOdent	Cross Sectional - In vitro	Human Premolars and Molars	TMR & Histology	Enamel=0.88; Dentin=0.90	E=0.83-0.87; D=76-0.84	E=0.72-0.78; D=79-0.87	E=0.79-0.84; D=0.81-0.83	-	-
Schneiderman et al., 1997[12]	DIFOTI	Cross Sectional - In vitro	Human Anterior and Posterior Teeth	Histology	0.52	0.67	0.87	-	-	-

E = Enamel; D = Dentin